

PARTIALLY PREMIXED FLAME (PPF) RESEARCH FOR FIRE SAFETY

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ABSTRACT

Incipient fires typically occur after the partial premixing of fuel and oxidizer. The mixing of product species into the fuel/oxidizer mixture influences flame stabilization and fire spread. Therefore, it is important to characterize the impact of different levels of fuel/oxidizer/product mixing on flame stabilization, liftoff and extinguishment under different gravity conditions. With regard to fire protection, the agent concentration required to achieve flame suppression is an important consideration. The initial stage of an unwanted fire in a microgravity environment will depend on the level of partial premixing and the local conditions such as air currents generated by the fire itself and any forced ventilation (that influence agent and product mixing into the fire). The motivation of our investigation is to characterize these impacts in a systematic and fundamental manner.

UIC-NASA PPF Drop Rig

(a) General Description

The UIC-NASA PPF drop rig includes equipment for performing normal- and reduced-gravity partially premixed flame experiments. The rig is equipped with two fuel storage tanks that have a volume of 0.5 L and can be filled to a maximum pressure of 250 psi. Various fuel, oxidizer, and diluent combinations can be stored in these tanks. For safety reasons, the mixtures utilized are outside the flammability limits. Both the inner and outer flows are supplied independently by using mixtures in two separate tanks. The gas flows are metered by on board MKS mass flow controllers that have a maximum range of 5 L/min for the inner flow and 20 L/min for the outer flow and are rated accurate within 1% of their maximum ranges. A variety of burners can be enclosed within a standard NASA supplied chamber. For normal atmospheric tests in the 2.2 Second Drop Tower, the chamber is not sealed.

(b) Diagnostics:

Several diagnostic techniques have been employed in the rig to examine partially premixed flame behavior: (i) A color CCD video camera is used to record the transient visible structure of the flames in normal and microgravity. (ii) Temperature measurements have been made using a thermocouple rake. (iii) Global radiation measurements through the use of a thermopile type radiometer have provided valuable heat loss information. Other diagnostics currently being developed for implementation during the next research phase (2004-2006) are: (i) A rainbow schlieren deflectometry (RSD) system for accurate nonintrusive temperature measurements, and (ii) Light intensity attenuation system for measuring soot loading in the flame.

Example Results

(a) Fundamental Research on Partially Premixed Flames

Our investigations have characterized the behavior of partially premixed flames in microgravity environments through observations of the transient flame structure, temperature profiles, and global radiation. These measurements have supplemented by detailed numerical simulations that have been extensively validated. The gravity-dependent behavior of the flames was characterized in terms of flow dilation, buoyancy, and radiation heat loss. These results will be published in the *Proceedings of the 30th International Symposium on Combustion* [1].

(b) Fire Safety Research

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Experiments are underway to investigate flame liftoff and blowout in normal- and microgravity from a fire safety perspective. The premixed fuel-air streams are diluted with nitrogen in order to simulate the entrainment of inert product species into a fire. Nitrogen addition is found to raise the Schmidt number sufficiently to allow for flame liftoff, i.e., that product diluted flames may in some cases detach and cause secondary fires at some distance from the reactant source. The effects of the reactant stoichiometry and flow conditions are being investigated for these lifted flames. In all cases, we find lifted flames to be much more stable in microgravity due to the removal of buoyancy-induced instabilities. In most cases the flame moves closer to the reactant source in microgravity relative to its normal gravity location clearly illustrating that normal gravity results are inadequate to describe microgravity flames and, therefore, fires. Moreover, different fuel/air concentrations have different effects on flame liftoff under the influence of gravity. Preliminary results on these aspects have been presented at the 42nd AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, Jan. 5-8, 2004 [2].

Our experiments also consider the influence of other diluents on these lifted flames, such as carbon dioxide and argon. These diluents are the primary components of non-halon gaseous fire extinguishing agents. The two inert species influence the flames differently. One reason arises from their differing heat capacities. They also inhibit the burning intensity, since they increase the third body concentrations and, therefore, influence the combustion chemistry. The diluents have differing radiation emission properties, which impact the heat losses from these flames. Differences between normal- and microgravity flame lift off and blow off may also be impacted by buoyancy driven instabilities and the contribution of diluent species properties to instability characteristics, such as their amplitude. Our investigation hopes to elucidate these issues in a fundamental manner to facilitate the appropriate fire safety strategies.

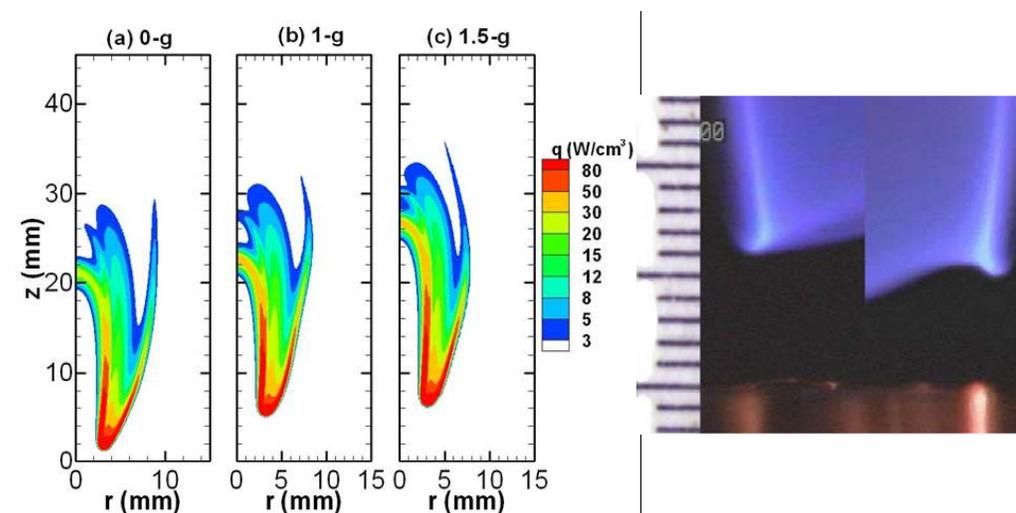


Figure 1: Influence of gravity on the liftoff height of a nonpremixed flame established on a coannular burner. Left: results of detailed numerical simulations. Right: normal- and microgravity experiments.

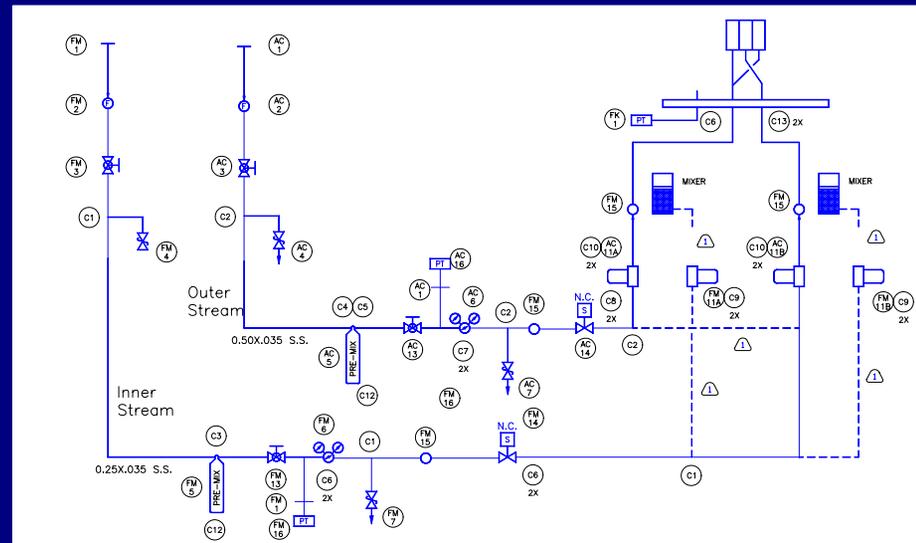
1. Lock, A., Ganguly, R., Puri, I. K., Aggarwal, S. K., and Hegde, U., "Gravity Effects on Partially Premixed Flames: An Experimental-Numerical Investigation", to appear in *Proceedings of The Combustion Institute*, **30**, 2004.
2. Lock, A., Qin, X., Ganguly, R., Puri, I. K., Aggarwal, S. K., and Hegde, U. "Lifted Partially Premixed Flames in Microgravity", *42nd Annual AIAA Aerospace Science Meeting and Exhibit*, Reno NV, January 2004

PPF Drop Rig

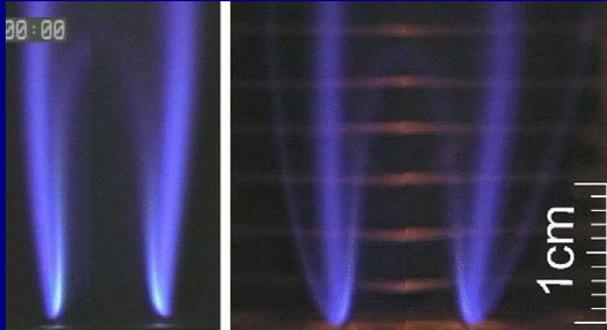


- Flexible and reliable piece of equipment.
- May be used in several microgravity facilities.
- Designed to investigate Partially Premixed Flames (PPFs)
- Flexible diagnostics platform.
- Designed and operated by Professor Ishwar K. Puri (VT), Professor Suresh K. Aggarwal (UIC), and Dr. Uday Hegde (NASA GRC).

- Equipped with two fuel storage tanks.
- Various Fuel/Oxidizer/Diluent combinations are used outside of flammability limits.
- Jet Flames investigated on slot burner and coaxial coflowing burners.
- Precision flow control, data acquisition, and control systems located on-board.



Drop Rig Diagnostics

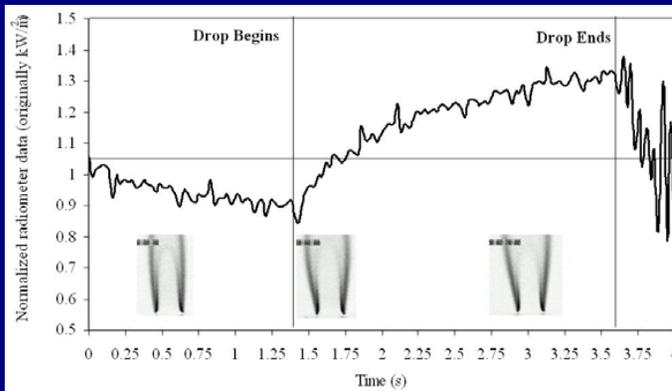
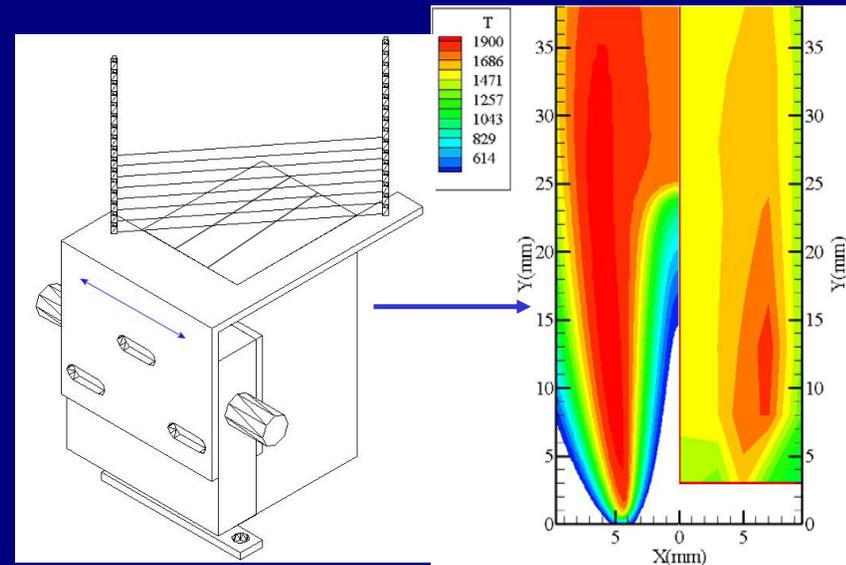


Color CCD Camera

- Focused on flame
- Video remotely recorded

Thermocouple temperature measurements

- Eight type R thermocouples
- Onboard data acquisition
- Results provide direct comparison with simulation



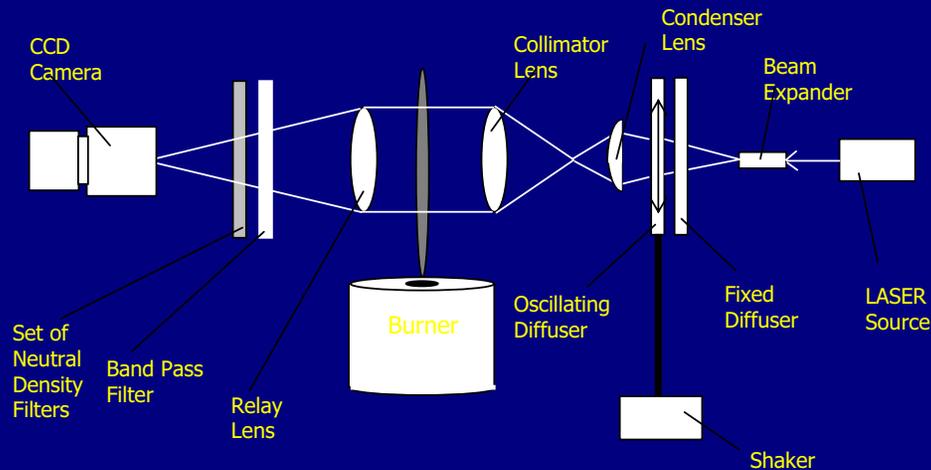
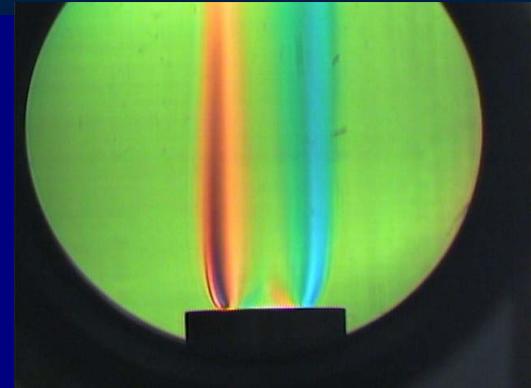
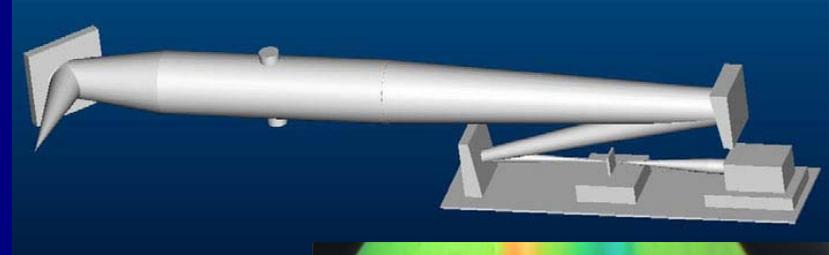
Radiometer global radiation measurement

- Thermopile type radiometer
- Onboard data acquisition via Tattletale
- Results provide insight into global radiation heat loss

Future Diagnostics

Rainbow Schlieren Deflectometry

- Non-intrusive temperature measurement
- Better temperature resolution
- Better temporal resolution
- Laboratory scale system working
- Rig design has been prototyped
- Next phase of rig development



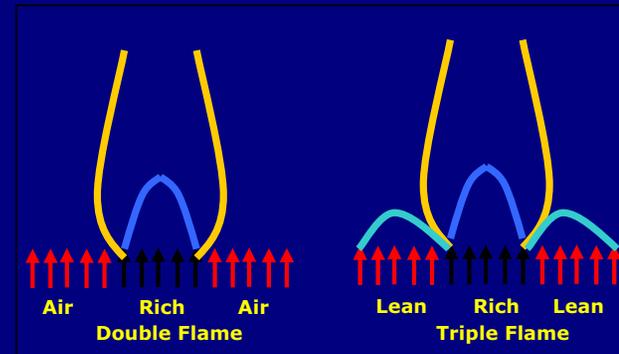
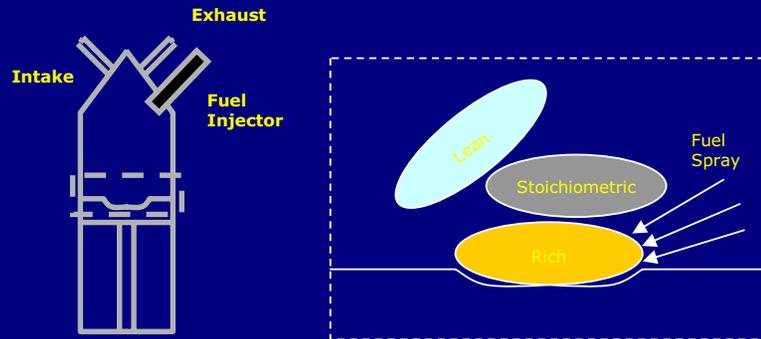
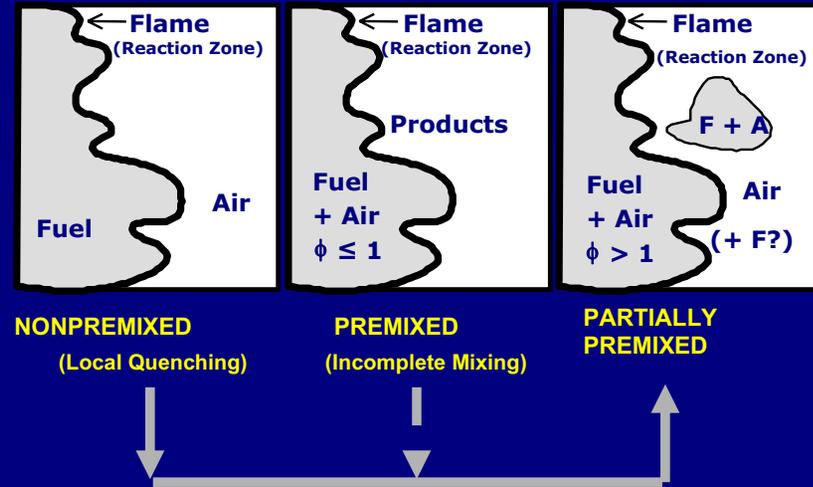
Soot Volume Fraction

- Non-intrusive soot measurement
- Provides 2-D field data
- Good temporal resolution
- Next phase of rig development

Partially Premixed Flames

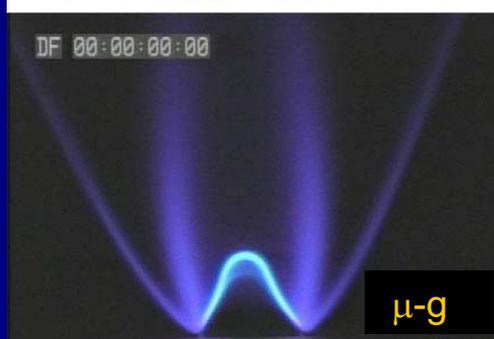
Characteristics of PPFs

- Non-uniform fuel-air mixing
- Different flammability characteristics from those of fully premixed and nonpremixed
- Produce two or more reaction zones
- Occur naturally in many practical applications
- Partially premixed regions are formed by gaseous fuel leaks and in evaporating liquids



Adapted from Wehrmeyer et al., C&F, 128, 232 - 241 (2002)

Gravity Effect on attached PPFs

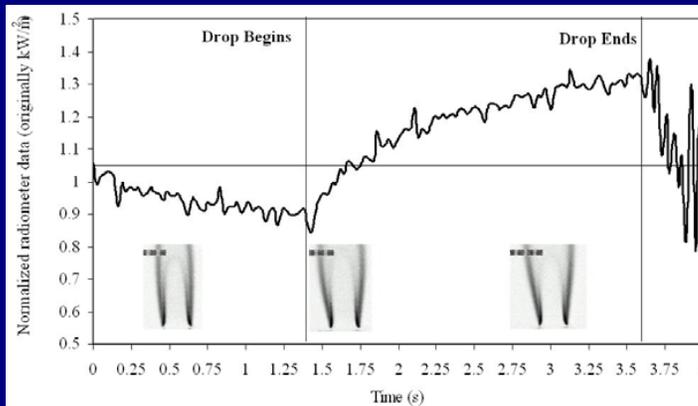
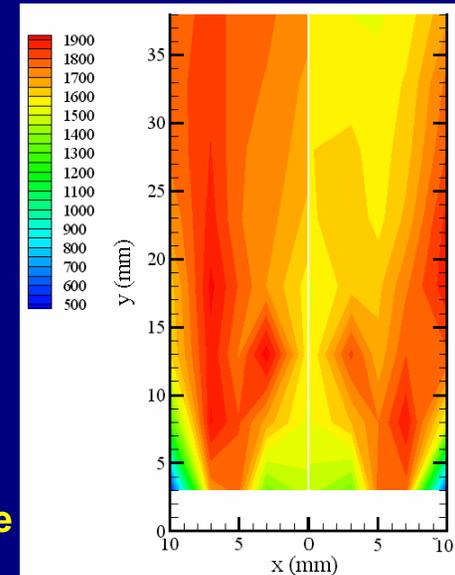


Flame Structure Changes

- Loss of buoyancy spreads flame, larger flame separation
- Tip opening occurs which may allow for partial oxidation components to escape

Flame Temperature Field Changes

- Temperature field spreads with reaction zones
- Mean temperature decreases
- Maximum temperature decrease



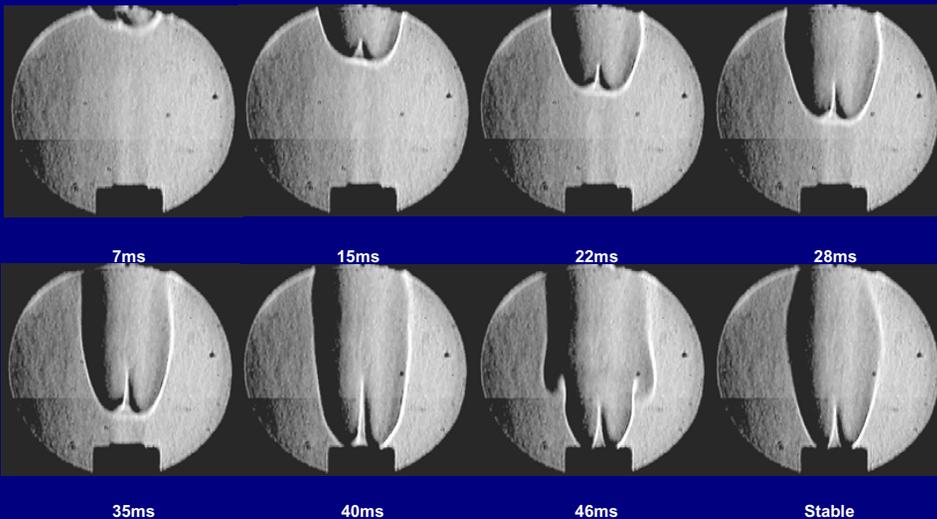
Flame Radiation Heat Loss

- Loss of buoyancy allows for longer residence time
- Flame volume occupies a larger volume
- The radiation heat loss from the flame increases substantially in microgravity

Fire Safety

Gas Leaks Produce Partially Premixed Regions

- Image shows raw rainbow schlieren image of a leaking pipe
- The varying color indicates varying degrees of premixedness
- The partial premixing creates a fuel concentration gradient



Ignition Above a Partially Premixed Jet

- Flame propagates back to source
- Buoyancy affects the propagation speed
- The flame propagates faster in microgravity

Lifted PPFs



$\phi_{in}=2.5, \phi_{out}=0,$
 $V=50\text{cm/s}$
 25% N₂ Diluent

$\phi_{in}=2.5, \phi_{out}=0,$
 $V=50\text{cm/s}$
 25% Ar Diluent

$\phi_{in}=2.5, \phi_{out}=0,$
 $V=50\text{cm/s}$
 20% CO₂ Diluent

- Introduction of inert diluent raises Schmidt number and allows methane-air PPFs to be lifted

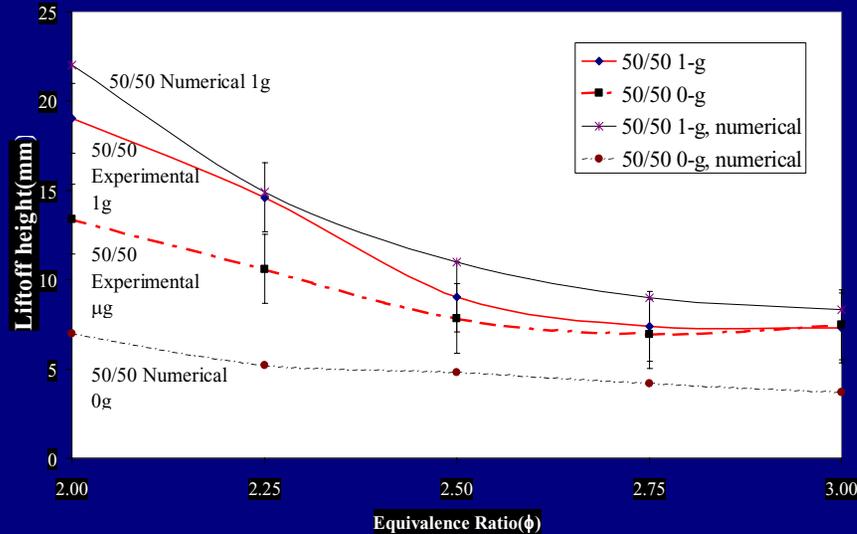
- Different diluents produce different effects

- N₂, Ar, and CO₂ are common components of non-halon fire suppressants

- Reduction of gravity influences flame liftoff and propagation

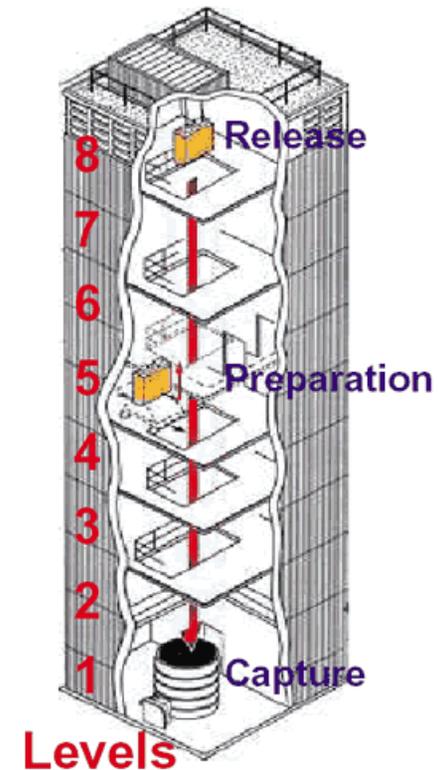
- Microgravity flames, but which blow out in normal gravity, may be stabilized

Liftoff Height vs. Equivalence ratio



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A cutaway drawing of the 2.2 Second Drop Tower, showing the levels on which an experiment package is prepared, released, and captured.

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